Life-Cycle Assessment for Mitigating the Greenhouse Gas Emissions of Retail Products

Arpad Horvath
Associate Professor
Department of Civil and Environmental Engineering
University of California, Berkeley

Eric Masanet
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

August 9, 2007

Consortium on Green Design and Manufacturing

Consortium on Green Design and Manufacturing

A Multi-Disciplinary Research and Educational Partnership Between Industry, Government, and Academia.

Since 1993

http://cgdm.berkeley.edu

- Multidisciplinary campus group integrating engineering policy, public health, and business in green engineering, management, and pollution prevention
- Strategic areas:
  - » Civil infrastructure systems
  - » Electronics industry
  - » Servicizing products
- 9 faculty from Civil and Environmental Engineering, Mechanical Engineering, Haas School of Business, Energy and Resources Group, School of Public Health
- 10 current Ph.D. students
- 28 alumni

Outline of Presentation

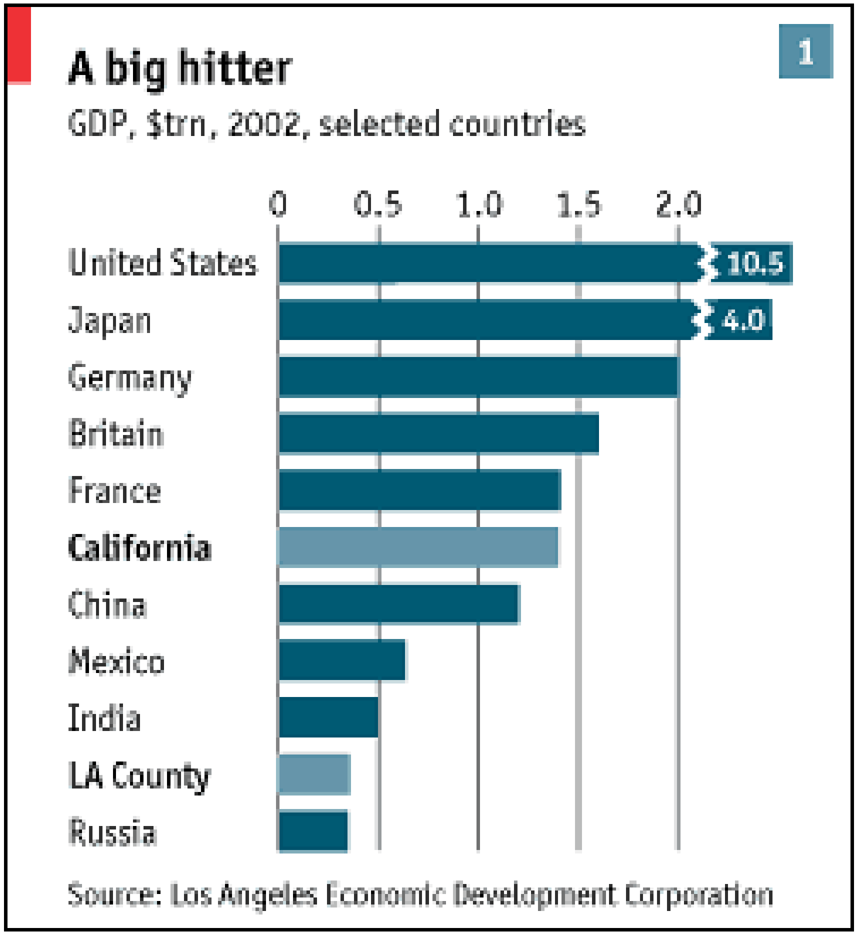
- Our proposed ARB project
- “Carbon footprint” research
- The role of the consumers
- Approach and methods
- Example
- Research challenges

Our Research Proposal to ARB

- "*Retail Climate Change Mitigation: Life-cycle Emission and Energy Efficiency Labels and Standards*"
  - Partners: A. Horvath (UCB), E. Masanet (LBNL), S. Matthews and C. Hendrickson (Carnegie Mellon University)
- Assess opportunities for reducing California's greenhouse gas (GHG) emissions through the life-cycle of retail products and services that Californians consume that occur both inside and outside of California.
  - ~ 2/3 is due to product manufacture, but use and end of life stages are also significant.
- Create a life-cycle assessment (LCA) model for California.
- Estimate the life-cycle GHG emissions of 20-30 key retail products consumed by Californians.
- Analyze the potential GHG emissions reductions achievable through the adoption of life-cycle GHG emissions policies for labels and standards for retail products in California over the next five years.

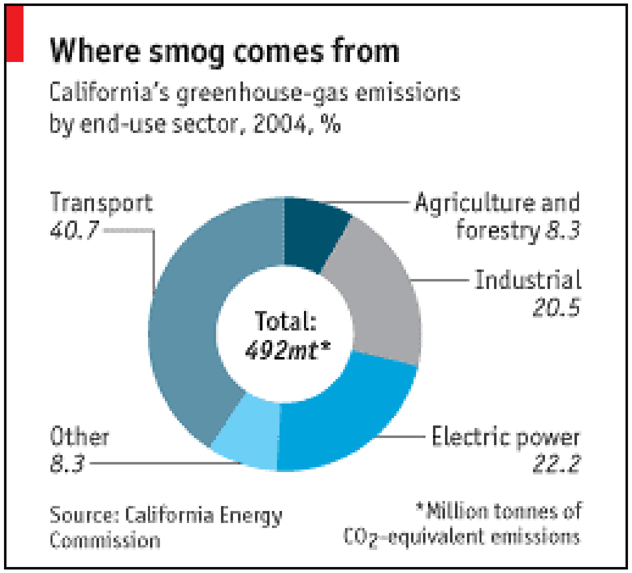
Exciting Times in California

- AB 32 *Global Warming Solutions Act*
  - » by 2020, return GHG emissions to 1990 levels (and boost annual GSP by $60B and create 17,000 jobs)
  - » By 2050, drop 80% below 1990 levels
- Increasing consumption
- Increasing population
- Major market of U.S. carbon offset demand

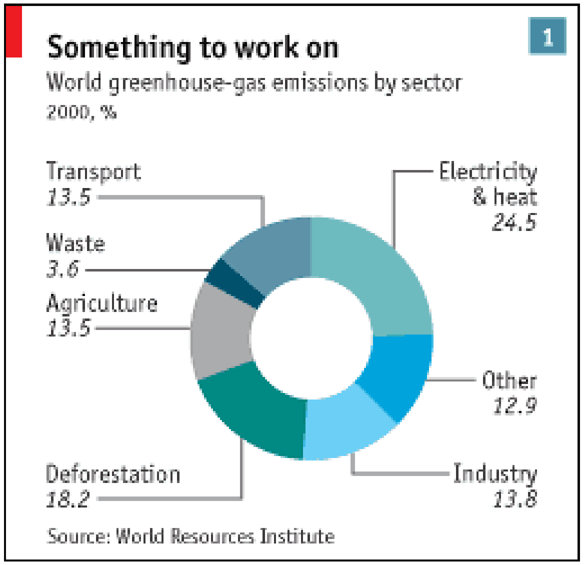


The Economist, 4/29/04

GHG Reduction Potential



The Economist, 6/21/07



The Economist, 5/31/07

View of the Economy: Input-Output Model

	Input to sectors				Intermediate output O	Final demand F	Total output X
Output from sectors	1	2	3	n			
1	X_{11}	X_{12}	X_{13}	X_{1n}	O_1	F_1	X_1
2	X_{21}	X_{22}	X_{23}	X_{2n}	O_2	F_2	X_2
3	X_{31}	X_{32}	X_{33}	X_{3n}	O_3	F_3	X_3
n	X_{n1}	X_{n2}	X_{n3}	X_{nn}	O_n	F_n	X_n
Intermediate input I	I_1	I_2	I_3	I_n			
Value added V	V_1	V_2	V_3	V_n		GDP	
Total input X	X_1	X_2	X_3	X_n			

$\sum X_{ij} + F_i = X_i$; $X_i = X_j$; using $D_{ij} = X_{ij} / X_j$

$\sum (D_{ij} * X_j) + F_i = X_i$

in vector/matrix notation:

$D*X + F = X \Rightarrow$ $F = [I - D]*X$

or $X = [I - D]^{-1}*F$

For more: www.eiolca.net

Role of the Consumer

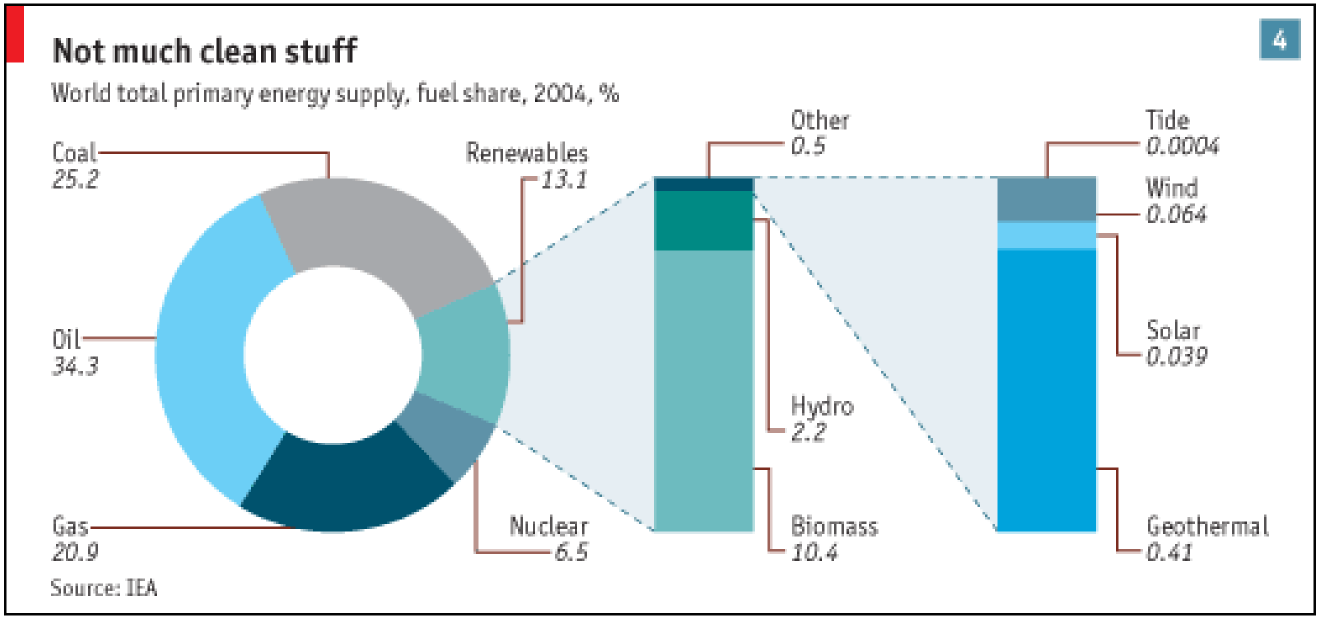
- Up to 80% of the annual greenhouse gas (GHG) "footprint" of the average U.S. consumer is attributable to the purchase, use, and disposal of retail products (Matthews, 1999, Carnegie Mellon U.)
- Consumer is guessing, at best
  - » SUV v. compact car
  - » Incandescent v. compact fluorescent
  - » but paper v. plastic cups? bags?

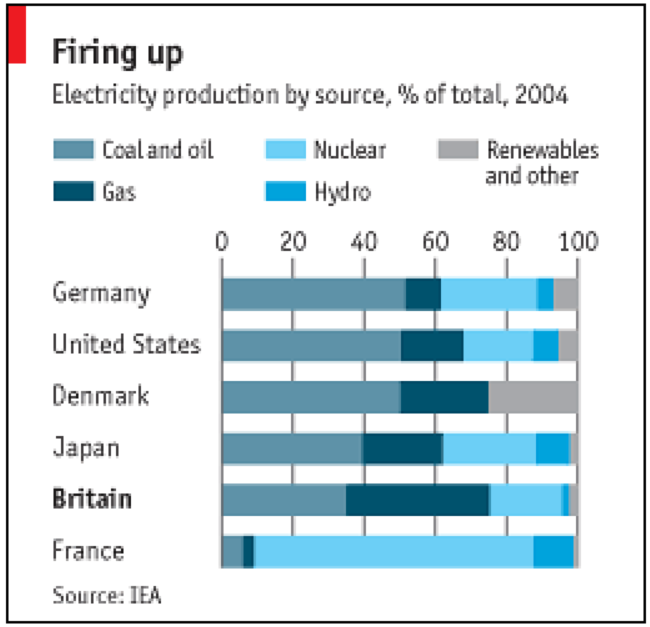
The Economist, 5/31/07

- Someone is picking "the right answer" for the consumer
  - » e.g., "green" electricity

Need Life-cycle Thinking!

- We don't always account for all environmental impacts





The Economist, 5/31/07

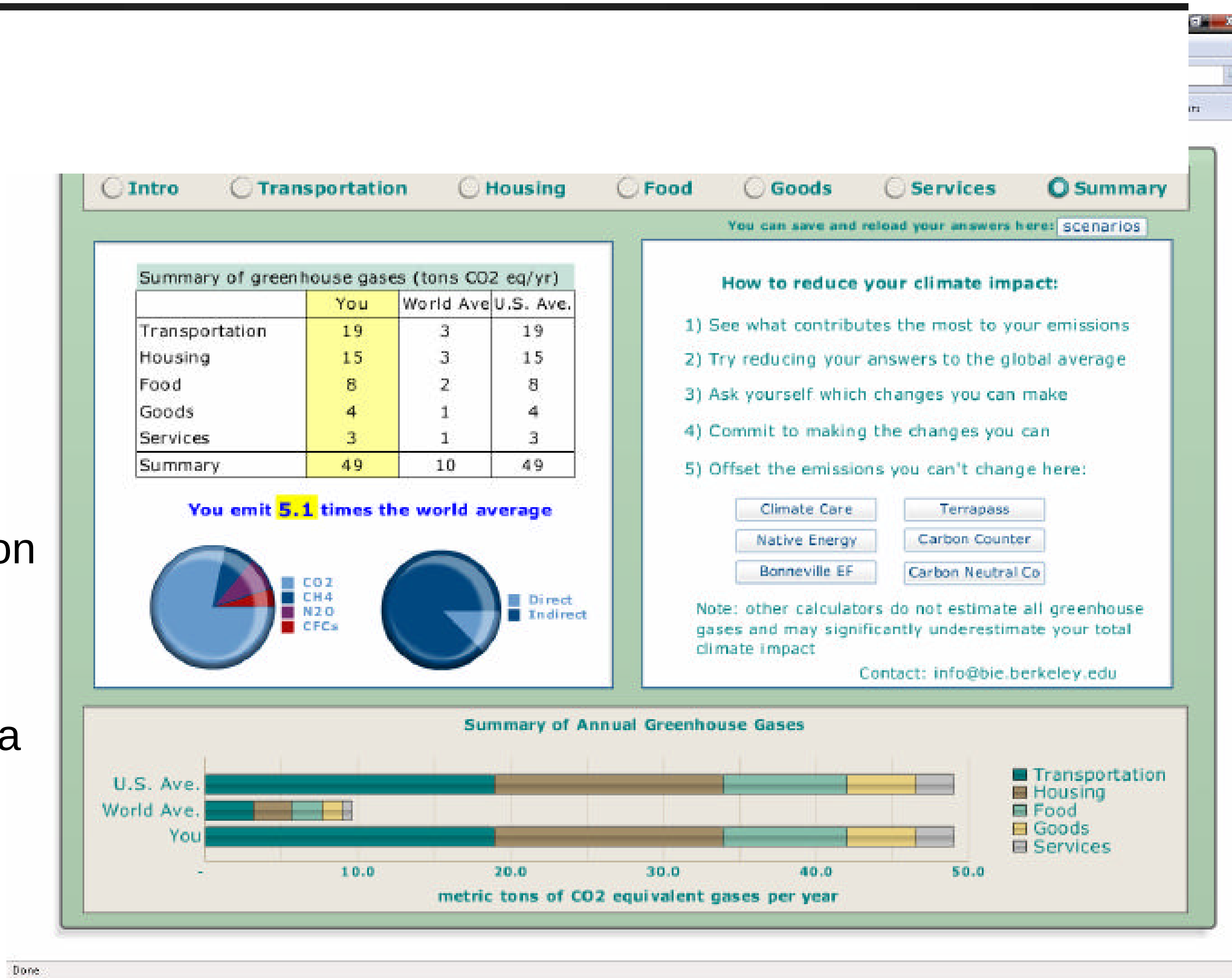
The Economist, 5/24/07

Life-cycle Environmental Assessment of Products and Services (LEAPS)

- www.consumerfootprint.org
- Chris Jones, cmjones@berkeley.edu

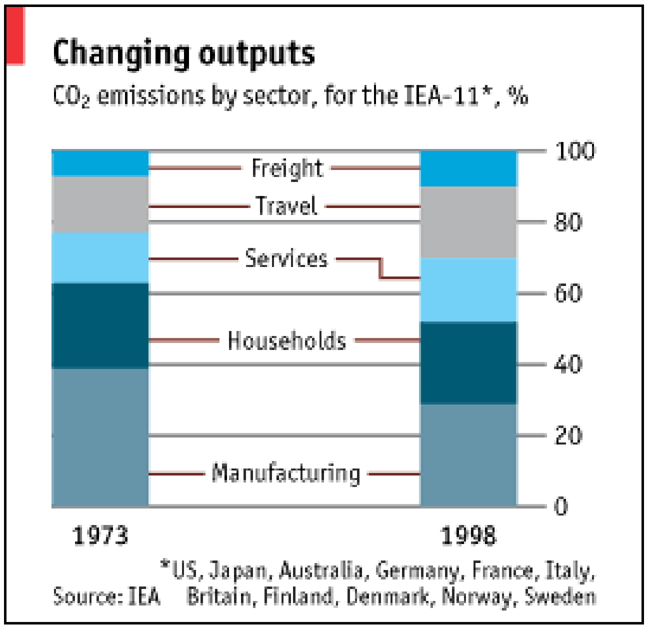
<u>Applications</u>

- Retailers: Carbon Neutral Shopping – point of sale, online, cards
- Consumers: Voluntary Carbon Offsets
- Manufacturers: Baseline Product-level Emissions Data



THE BERKELEY INSTITUTE OF THE ENVIRONMENT

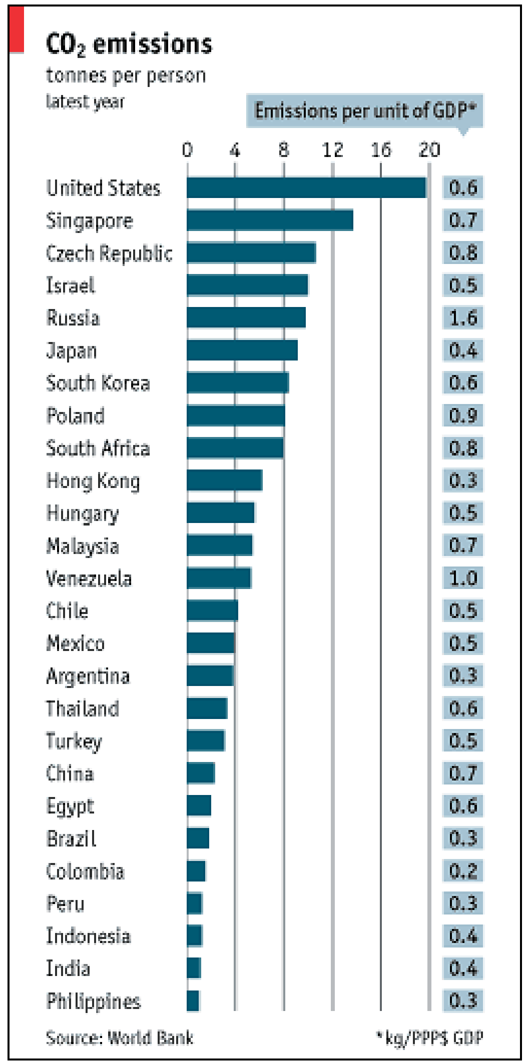
Opportunities to Influence Private Consumers

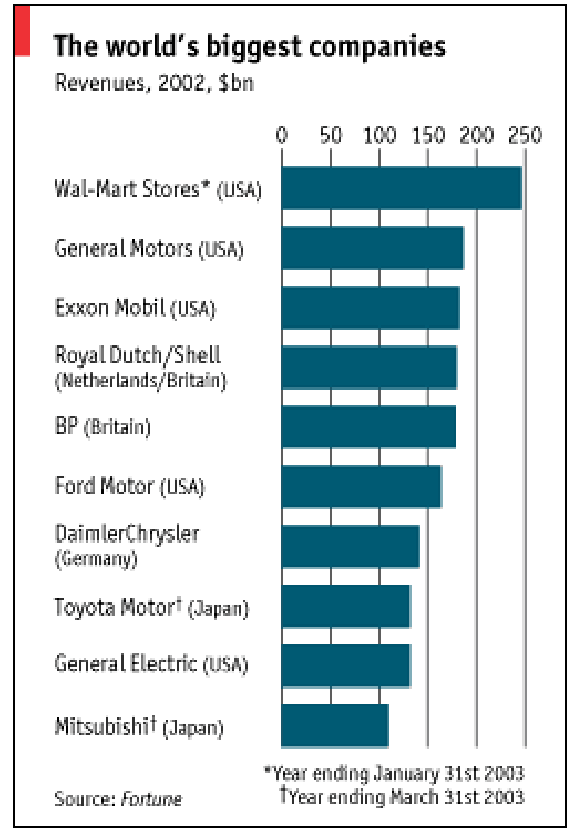


The Economist, 10/07/04

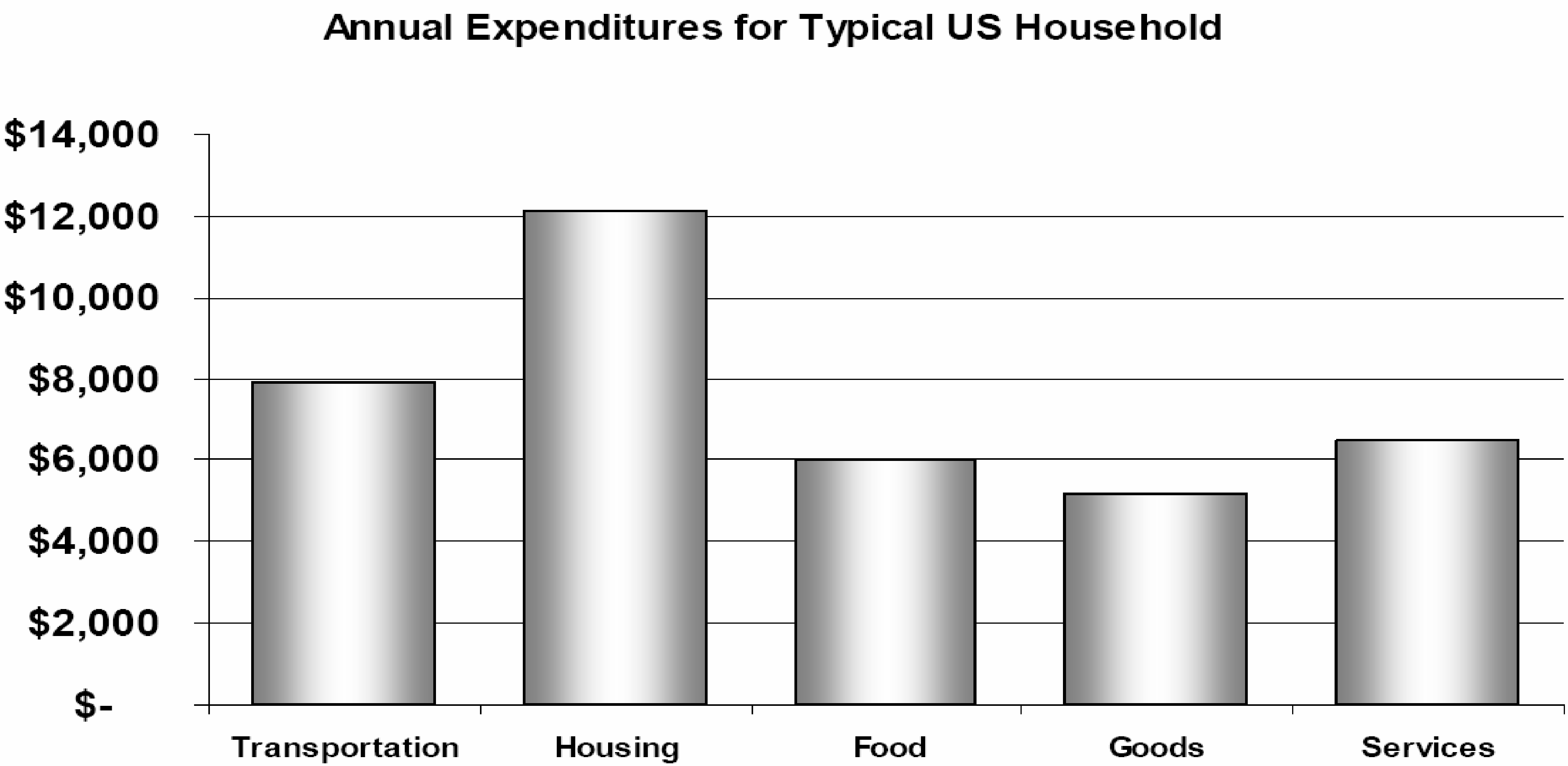
- Tesco (UK)
- Wal-Mart
- Home Depot

The Economist, 5/08/03





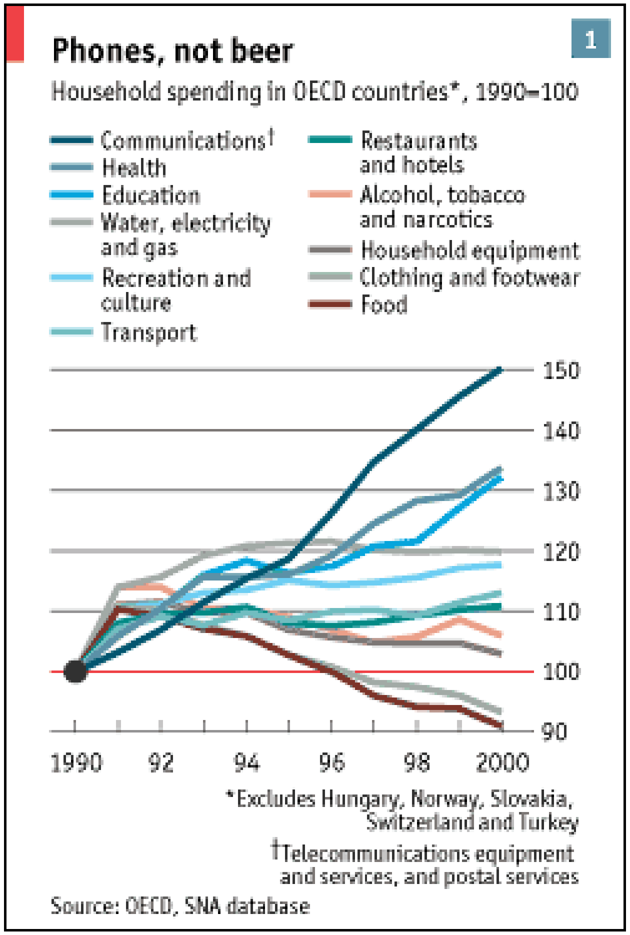
The Economist, 9/11/03



Consumer Expenditures Survey, 2004. U.S. Dept. of Labor Statistics

Courtesy of Chris Jones, BIE, UC Berkeley

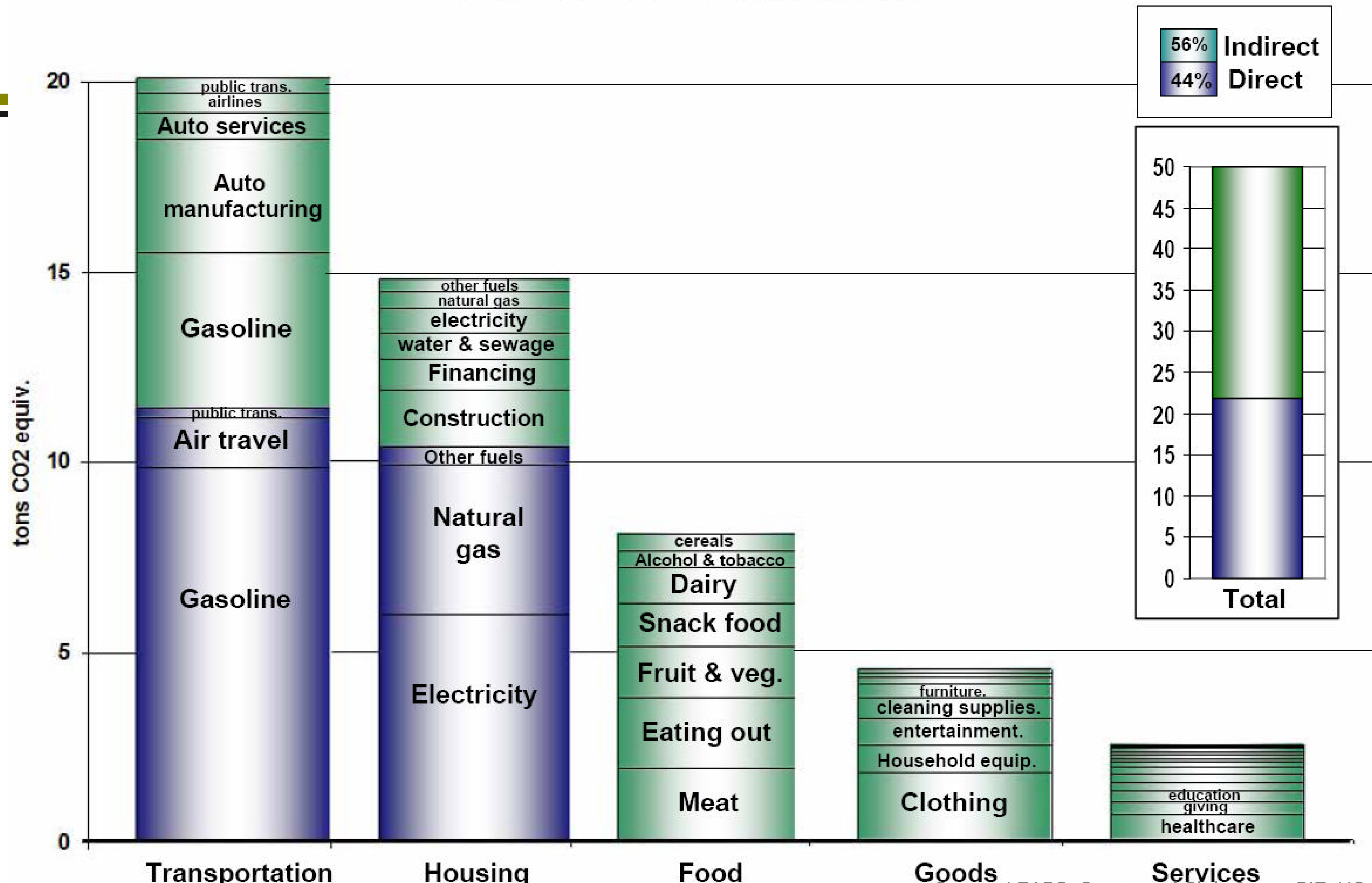
Changing Consumption Patterns



The Economist, 10/09/03

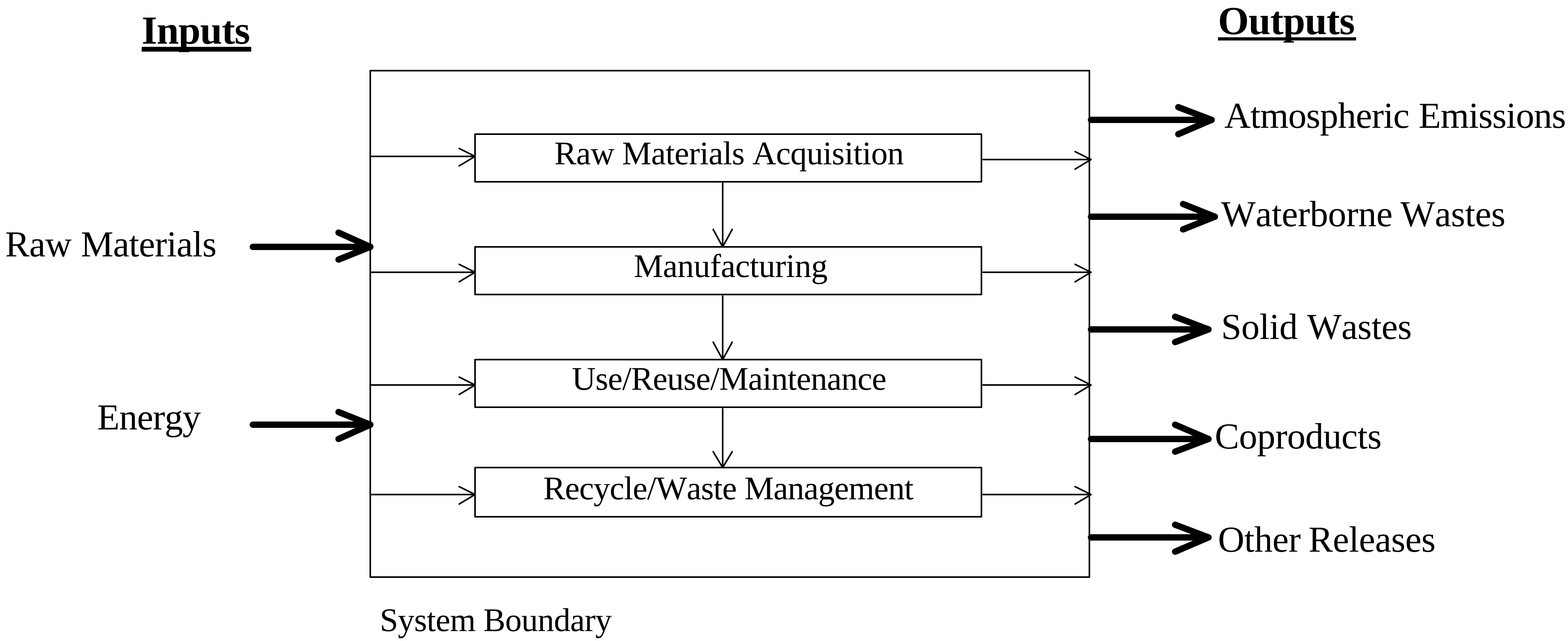
Summary of GHG Emissions for Typical U.S. Household

Metric tons of CO2 equivalent gases



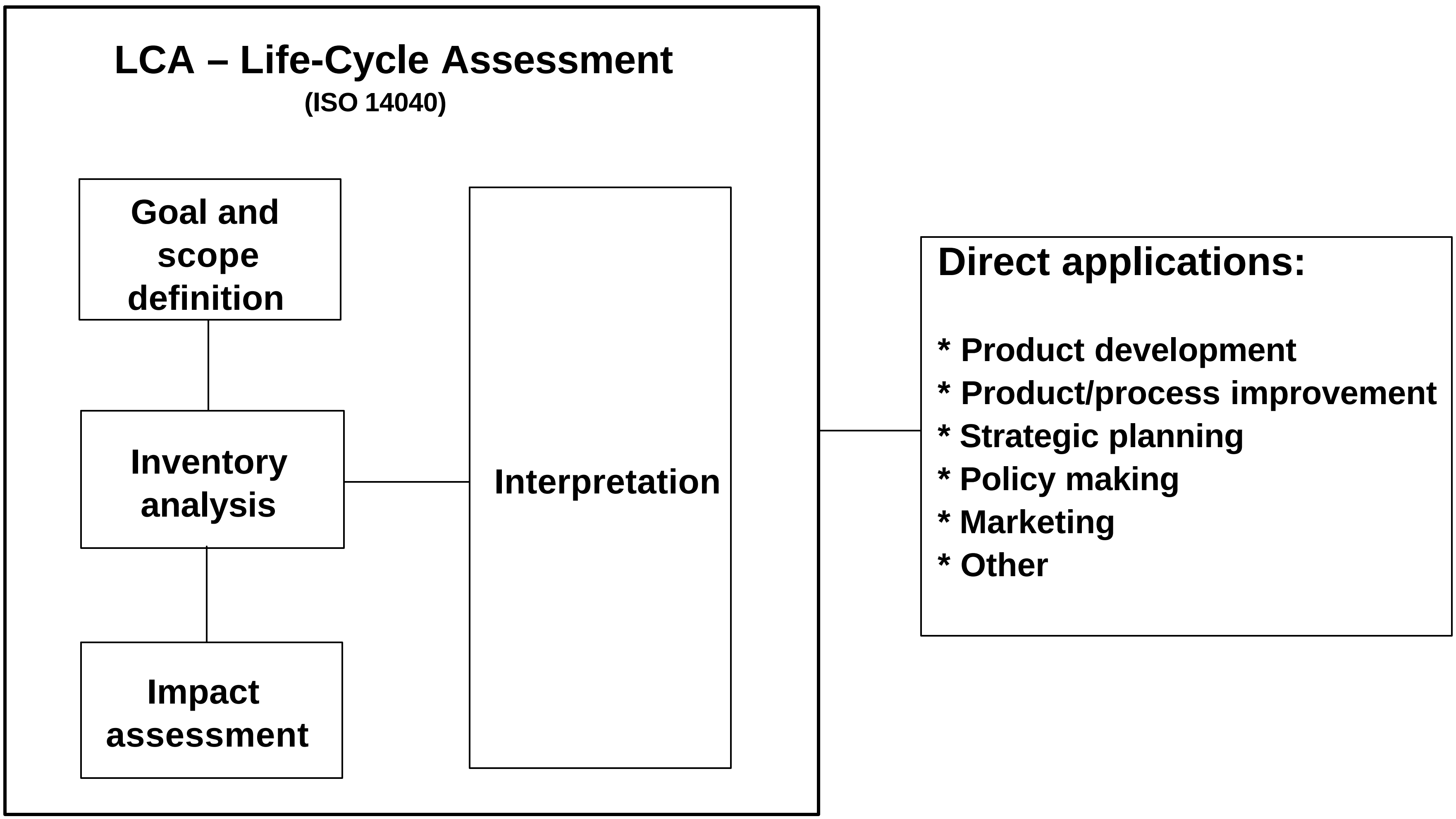
Source: LEAPS; Courtesy of Chris Jones, BIE, UC Berkele

LCA Framework



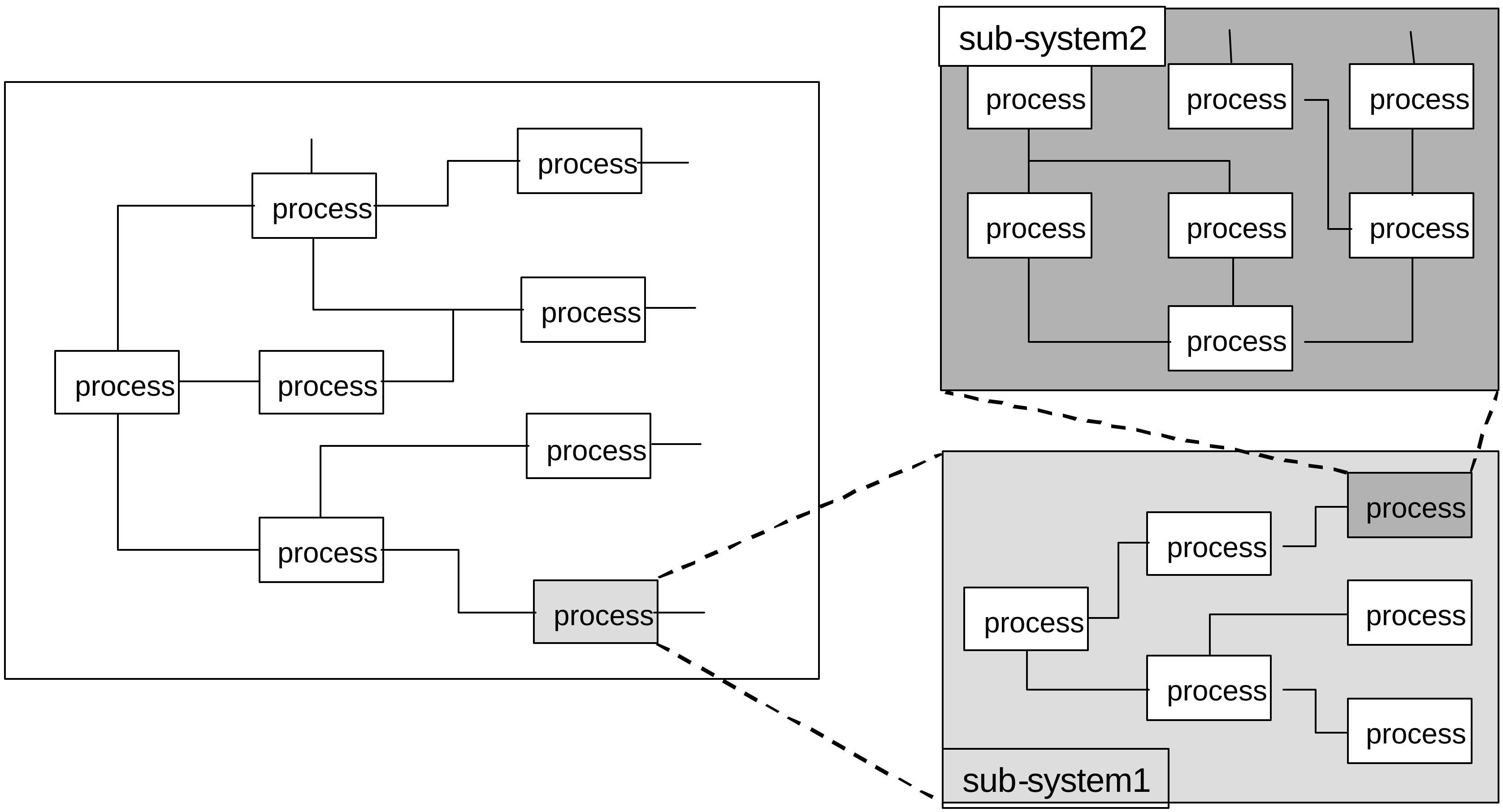
A concept and methodology to evaluate the environmental effects of a product or activity holistically, by analyzing the whole life cycle of a particular product, process, or activity (U.S. EPA, 1993).

LCA Methodology – ISO 14040

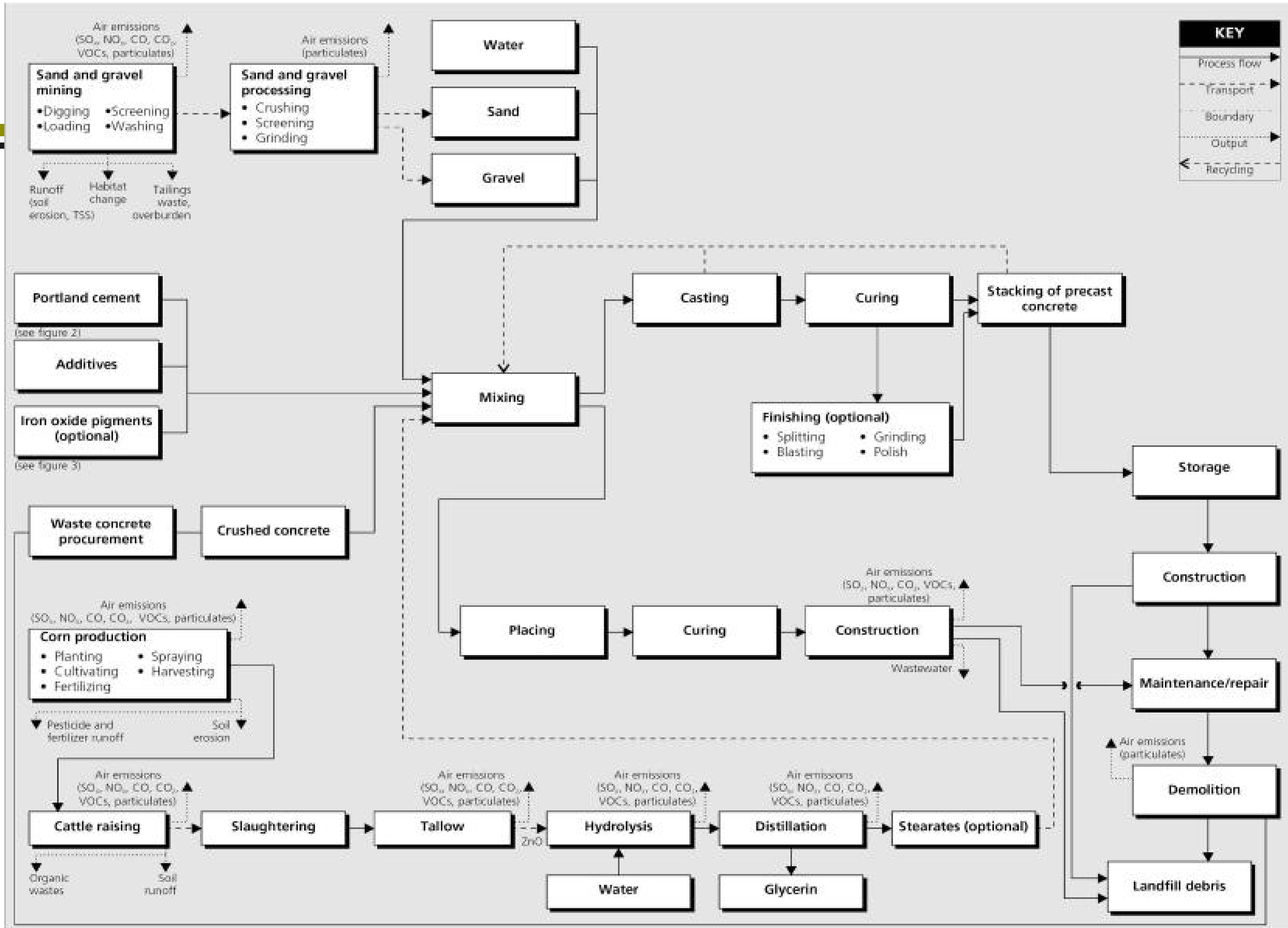


Source: U.S. EPA, 1993

Structure of a Process-based LCA Model



Process Flow of Cement Concrete

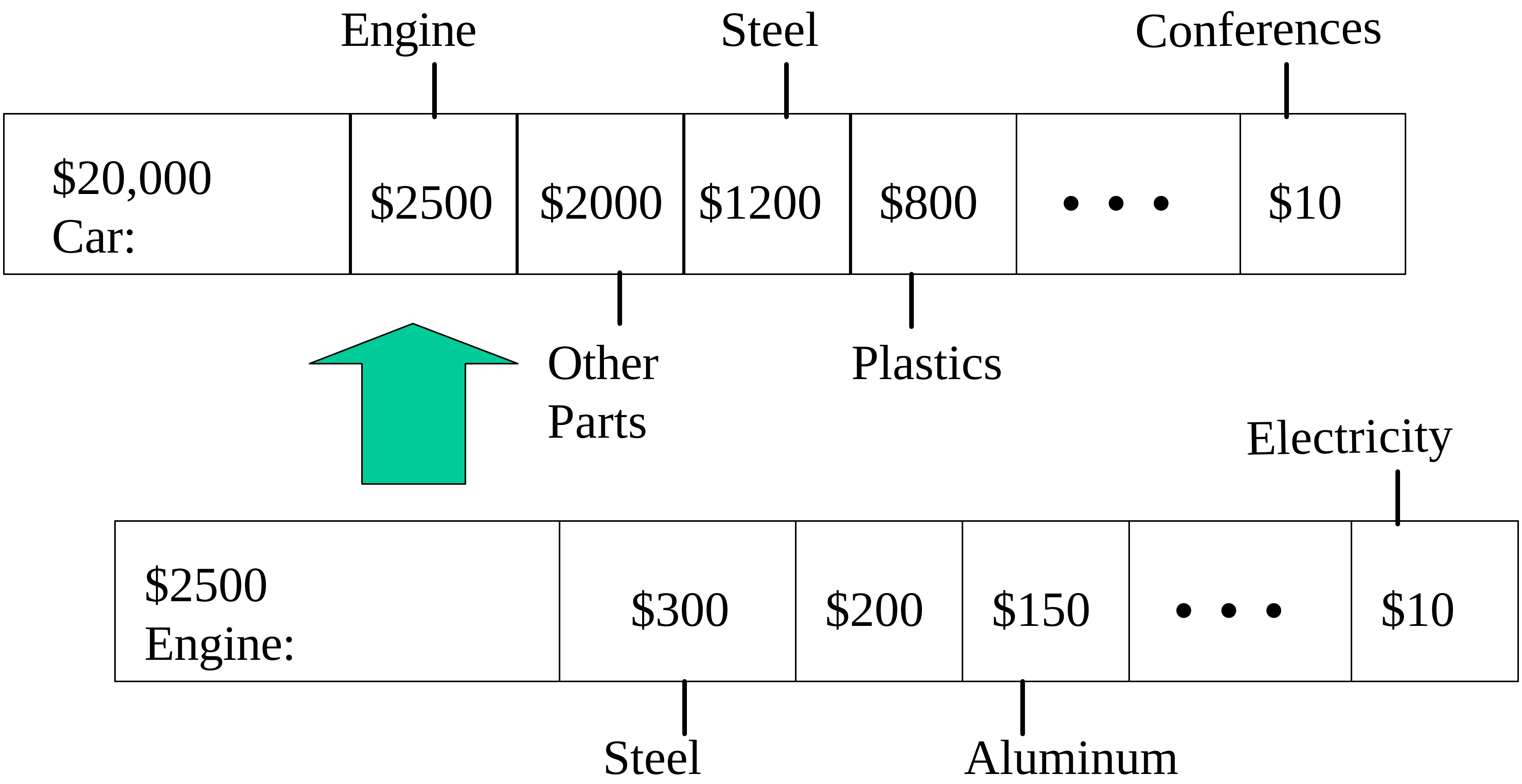


AIA, "Environmental Resource Guide," John Wiley & Sons, 1997

Economic Input-Output Analysis

- Developed by Wassily Leontief
  - Nobel Prize in 1973
- "General interdependency" model: quantifies the interrelationships among sectors of an economic system
- Identifies the direct and indirect economic inputs
- Can be extended to environmental and energy analysis

Economic I-O Analysis Visualization



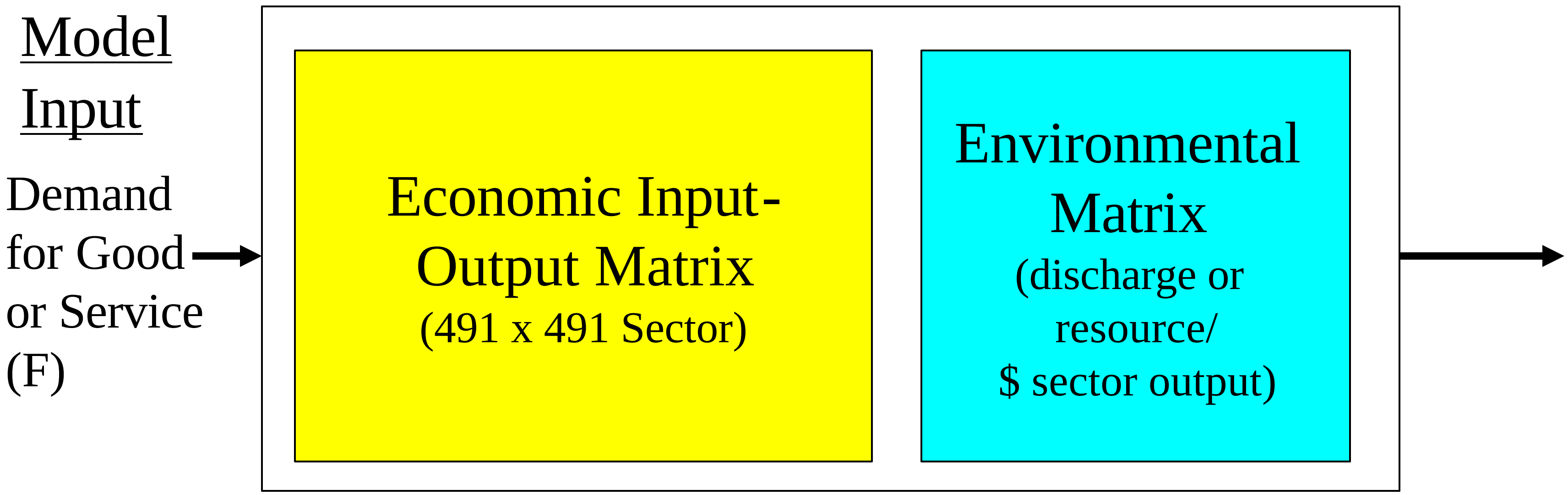
EIO-LCA Implementation

- Use the appr. 491 x 491 input-output matrix of the U.S. economy
  - 1992, 1997, soon 2002
- Augment with sector-level environmental impact coefficient matrices (R) [effect/$ output from sector]
- Environmental impact calculation:

$$E = RX = R[I - D]^{-1}F$$

- Available free at *www.eiolca.net*

Economic Input-Output Analysis-based LCA Model



Example of Model Output

	Economic	Energy	Iron Ore	NOx
Total	(1992$)	TJ	kg	kg
Motor Vehicles	x	e		
Steel				

$$X = F + DX$$

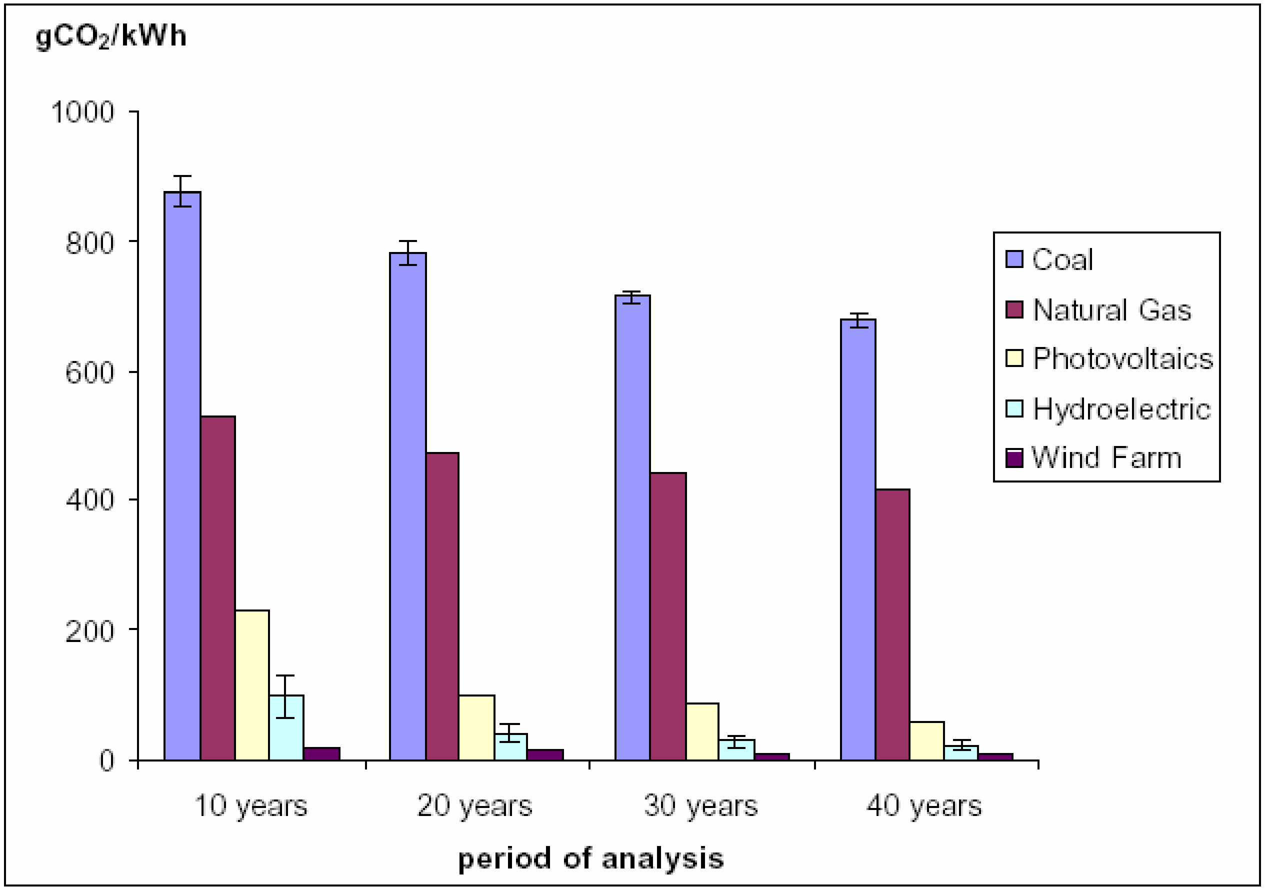
$$D_{ij} = X_{ij} / X_j$$

$$X = [I - D]^{-1} F$$

$$X = [I + D + D^2 + D^3 + \ldots]F$$

$$E = R\,X = R[I - D]^{-1} F$$

Comparison of Electricity Generation Technologies



Pacca, S., Horvath, A., "Greenhouse Gas Emissions from Building and Operating Electric Power Plants in the Upper Colorado River Basin." *Env.Sci.Techn*., 36(14), 2002, pp. 3194-3200

Approach and Methods (I)

1) Development of a California-specific LCA model for evaluation of goods and services

2) Assessment of average life-cycle energy use and GHG emissions for 20-30 key retail products

3) Estimation of lowest achievable life-cycle GHG emissions by product

4) Scenario analysis of technical potential for GHG emissions reductions via product life-cycle GHG emissions standards and/or labels

Approach and Methods (II)

1) Development of a California-specific LCA model for evaluation of goods and services
   - Production-phase energy use and GHG emissions:
     - California EIO-LCA
       - In-state versus out-of-state emissions
       - California economic sector-specific data
     - California consumer spending data
   - Use-phase energy use and GHG emissions:
     - California stock modeling
     - Typical operating energy use data
     - California-specific grid mix (base and peak loads)
   - Disposal-phase GHG emissions:
     - California waste disposal and recycling data

California EIO-LCA Model

- Based on national EIO-LCA approach
- Includes interstate and international commerce
  - » Weber and Matthews 2007 study: U.S. produced 22% of eCO_2 in 2005, but U.S. consumption accounted for 25-26%.
- Energy and environmental data from CA
- Preliminary model developed in 2005
  - » Annual GHG emissions arising from CA consumption of:
    - – Semiconductors in personal computers
    - – Pharmaceuticals

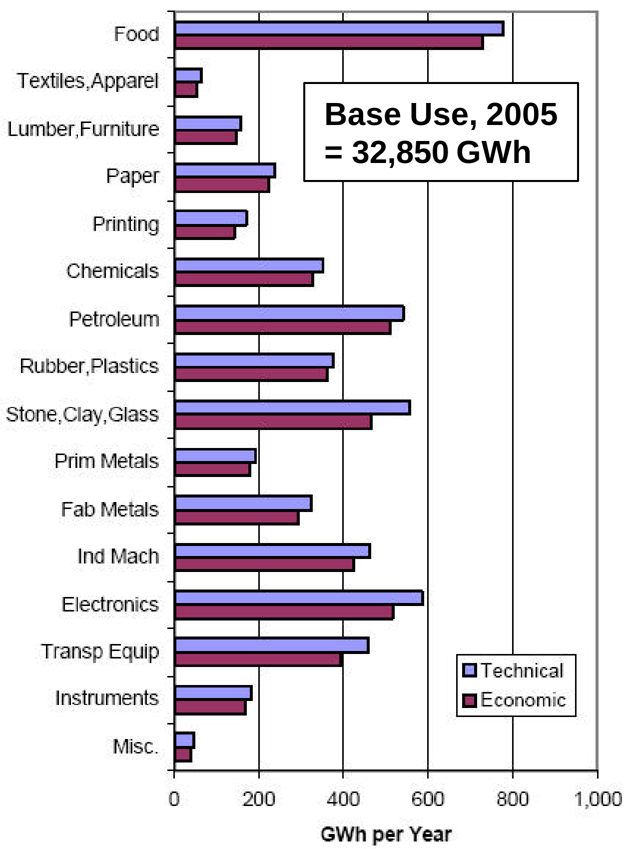
Approach and Methods (III)

2) Assessment of average life-cycle energy use and GHG emissions for 20-30 key retail products
   - Annual energy use and GHG emissions occurring both inside and outside of California
   - Selection based on major emitters and ARB input
3) Estimation of lowest achievable life-cycle GHG emissions by product
   - Based on best available technologies and practices at each life-cycle stage
     - Production: sector-level improvement potential analyses (worldwide)
     - Use: best-in-class energy efficiency (e.g., ENERGY STAR products)
     - Disposal: optimal waste treatment strategies (e.g., recycling, composting)
   - "Low carbon" versions represent minimum life-cycle GHG emissions achievable through California product standards and/or labels

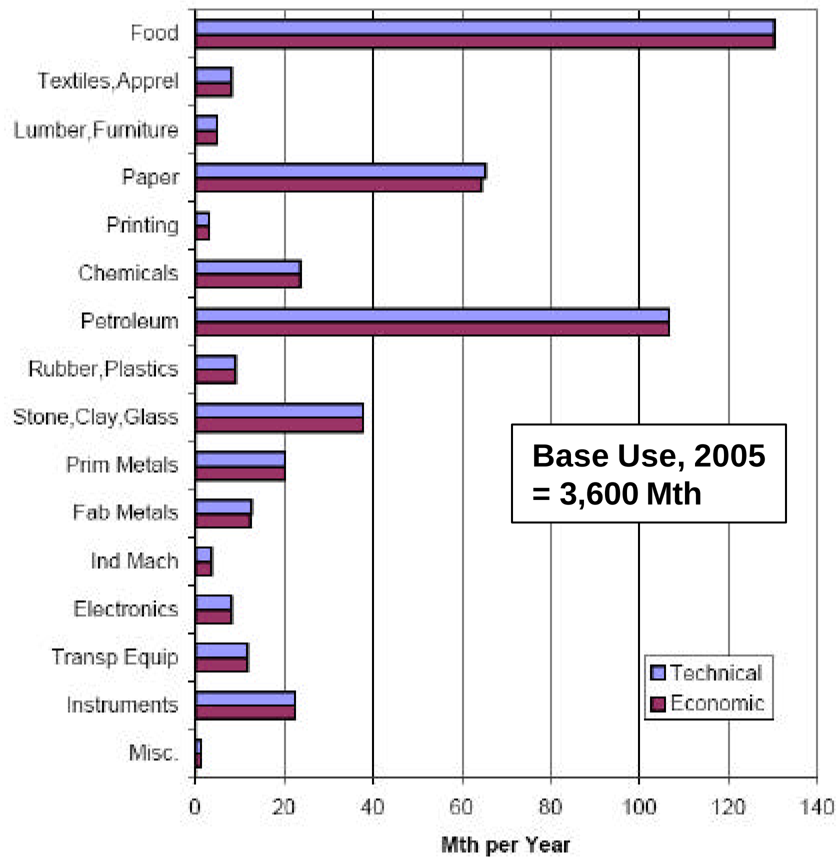
California Industrial Energy Efficiency Improvement Potential

Industrial Achievable Savings Potential by Industry, 2005

Electricity



Natural Gas



Source: KEMA (2006) California Industrial Existing Construction Energy Efficiency Potential Study

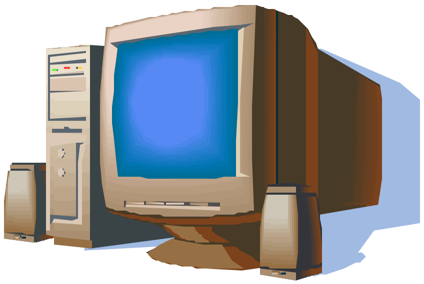
Approach and Methods (IV)

4) Scenario analysis of technical potential for GHG emissions reductions via product standards and/or labels
   - Five year analysis period
   - Specific to 20-30 retail product analyzed
   - Naturally occurring reductions based on product-specific analysis:
     - Stock turnover
     - Current energy efficiency and GHG reduction trends
   - Remaining technical potential estimated for:
     - “Low carbon” product standards (mandatory)
     - “Low carbon” product labels (voluntary)
       - » ENERGY STAR elasticity as proxy
     - Green purchasing programs

Illustrative Example: California PCs

Estimated California Installed Base of PCs, 2005

Market	Total PCs	Desktop PCs		Notebook PCs
		w/ CRT Monitor	w/ Flat Panel Display	
Residential	12,250,500	5,720,700	3,505,800	3,024,000
Commercial	6,718,600	3,189,000	1,862,100	1,667,500
Total	18,969,100	8,909,700	5,367,900	4,691,500



Source: Masanet, E., and A. Horvath (2006). "An Analysis of Measures for Reducing the Life-Cycle Energy Use and Greenhouse Gas Emissions of California's Personal Computers." University of California Energy Institute Technical Report, Berkeley, California.

Annual Life-Cycle GHG Emissions of California's Installed Base of PCs

Estimated Life-Cycle GHG Emissions, 2005

Life-Cycle Phase	GHG Emissions (10^6 Mg CO_2e)		Total
	Inside CA	Outside CA	
Production	0.2	3.2	3.4
Use	1.9		1.9
End of Life	-0.01	-0.13	-0.14
Total	2.1	3.1	5.2

- **Total is equivalent to the annual GHG emissions of 1.16 million automobiles (4,500 kg CO_2e per car per year) or 1.3% of California's net GHG emissions in 2004**

Source: Derived from (1) Masanet, E., L. Price, S. de la Rue du Can, R. Brown, and E. Worrell (2005). *Optimization of Product Life Cycles to Reduce Greenhouse Gas Emissions in California*. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-110; and (2) Masanet, E., and A. Horvath (2006). *An Analysis of Measures for Reducing the Life-Cycle Energy Use and Greenhouse Gas Emissions of California's Personal Computers*. University of California Energy Institute Technical Report, Berkeley, California.

GHG Emission Reduction Potential

Analysis of Select Policy Measures, 2005

Life-Cycle Phase	Measure*	Approximate Incremental Life-Cycle GHG Emission Reduction (%)**
Production	Improve manufacturing energy efficiency	6%
	Reduce PFC emissions from semiconductor manufacture	3%
Use	100% power management	8%
	Purchase ENERGY STAR v3.0 compliant PCs	1%
	Turn PC off during periods of non-use	2%
End of Life	Upgrade to extend PC life by 50%	7%
	Maximize recycling of PC control units	1%
Total		28%

* Measures are applied in a cascading fashion

** % reduction with respect to 2005 California PC life-cycle GHG emissions of $5.9*10^6$ Mg CO_2e

Source: Derived from (1) Masanet, E., L. Price, S. de la Rue du Can, R. Brown, and E. Worrell (2005). *Optimization of Product Life Cycles to Reduce Greenhouse Gas Emissions in California*. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-110; and (2) Masanet, E., and A. Horvath (2006). *An Analysis of Measures for Reducing the Life-Cycle Energy Use and Greenhouse Gas Emissions of California's Personal Computers*. University of California Energy Institute Technical Report, Berkeley, California.

Translation to “Low Carbon PC” Standard/Label

- **Minimization of production-phase energy use and GHG emissions**
  - Energy efficient supply chains (best practice, top quartile, etc.)
    - ➢ Example: clean room HVAC efficiency can often be improved by 30% to 60%
  - Reduced PFC emissions during semiconductor manufacture
  - Reporting of embedded energy use and GHG emissions
  - Minimum recycled content
  - Designed for ease of upgrading

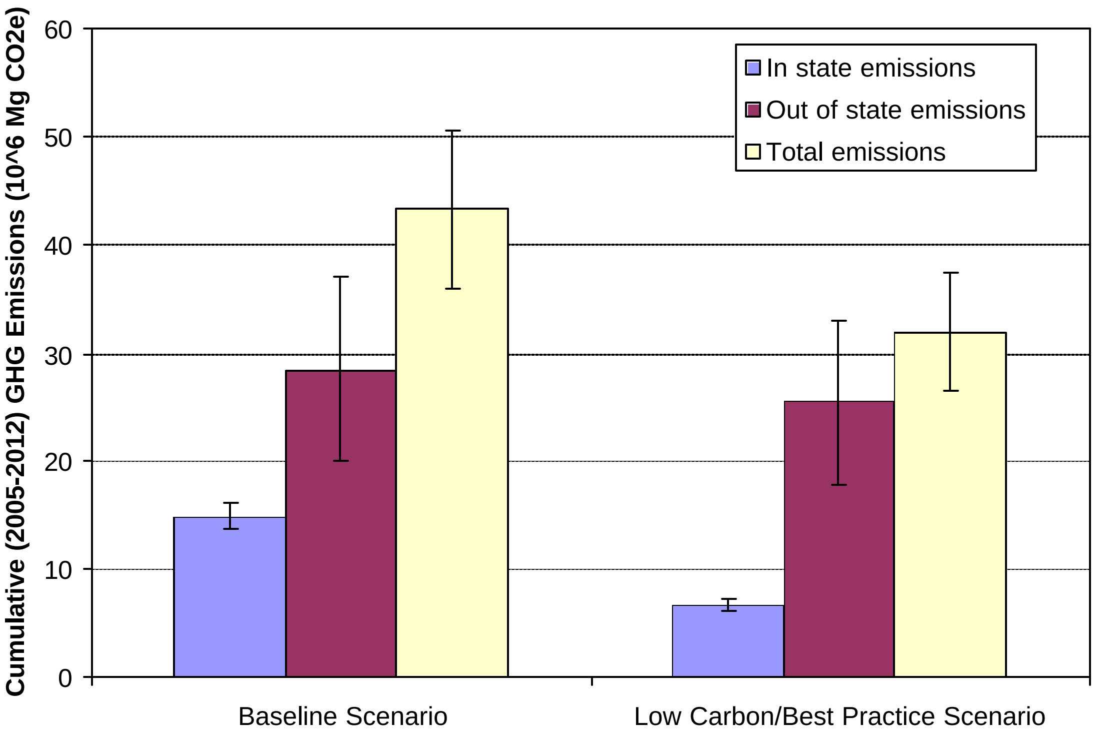
ENERGY STAR©

- **Minimization of use-phase energy use and GHG emissions**
  - Best in class energy efficiency (e.g., ENERGY STAR certified)
  - High efficiency power supplies, minimal standby losses
  - Flat panel displays versus CRT monitors
  - Power management enabled
  - IEEE 1621 compliant (ease of power management standard)

- **Minimization of disposal-phase energy use and GHG emissions**
  - Guaranteed take-back and recycling with full end of life fate reporting
  - In-state recycling of materials
  - Designed for recycling and ease of dismantling
  - Reduction/elimination of toxic constituents (RoHS, EPEAT, and beyond)

Technical Potential for GHG Emissions Reduction

Projected Cumulative Life-Cycle GHG Emissions of California PCs (2005-2012)



Technical potential for GHG emissions reductions:

Total = 11.3 10^6 Mg CO_2e

In state = 8.2 10^6 Mg CO_2e

Out of state = 3.1 10^6 Mg CO_2e

Source: Masanet, E., and A. Horvath (2006). "An Analysis of Measures for Reducing the Life-Cycle Energy Use and Greenhouse Gas Emissions of California's Personal Computers." University of California Energy Institute Technical Report, Berkeley, California.

Research Challenges

- Uncertainty
- Large number of consumer products
  - » Need to pick 20-30
  - » Significance and magnitude
- Dynamically changing supply chains
- Functional unit
- Design changes
- Updates over time

Contact Information:

Arpad Horvath
Associate Professor
Department of Civil and Environmental Engineering
University of California, Berkeley
horvath@ce.berkeley.edu
Tel.: 510-642-7300

Eric Masanet
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
ermasanet@lbl.gov
Tel.: 510-486-6794